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Perspective

Rethinking the future low-carbon city: Carbon neutrality, green design, and sustainability tensions in the making of Masdar City

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ABSTRACT

As the global trend toward urbanization continues, new models for the design and governance of sustainable cities are being developed. The Abu Dhabi government announced in 2006 its intent to spend $22 billion to build one such city, Masdar City, as a carbon-neutral, zero-waste city that would demonstrate the state-of-the-art in sustainable city design. As initially planned, Masdar City was a bold experiment: an incubator of clean-technologies that was to be powered exclusively by renewable energy while exhibiting the highest levels of energy efficiency. Partly due to the 2008 global financial crisis and partly due to lessons learned from continued assessments of the original concept, planners at Masdar both scaled back initial ambitions for the city's carbon and waste targets and significantly altered both the city's development approach and timeline for completion. This, however, may turn out to be the best outcome for Masdar City if it is truly to become a model for "eco-cities" of the future. Masdar now seeks a more commercial model that nonetheless retains a focus on sustainable urban design. This Perspective reviews the history of Masdar City from its inception to the present day and highlights the major changes that have occurred in its city planning. In consideration of the facts presented, Masdar City may yet emerge as a true eco-city. Regardless, it certainly constitutes an omen with incredibly important empirical lessons for other cities around the world seeking to become more sustainable.

1. Introduction

Today more than half of the world's population lives in cities, and by 2050 this number will increase to nearly 70% [1]. Cities will soon account for 90% of global population growth as well as about 75% of global carbon dioxide emissions and 75% of energy consumption [1,2]. Nonetheless, urbanization will continue because cities are where 80% of global wealth is created and they are where people find opportunities for work and socialization [1].

Unfortunately, rural to urban migration following the industrial revolution has led cities to grow rapidly and spontaneously in response to the evolving needs of inhabitants. This reactive, patchwork-like approach to city design has left many cities with inefficient layouts, technologies and infrastructure that consume large amounts of energy and water, and significant amounts of pollution [3]. Efficient and effective future city design and technology deployment, however, may very well be the key to unlocking social, economic and environmental sustainability.

The evolution and/or design of future cities that can sustainably meet these challenges depends on context, which includes population, population density and wealth [3]. Within a given context, a city's sustainability and performance depend on how technologies and policies are mobilized to enhance energy, water, waste, healthcare, mobility, security, economic development and community engagement [4]. They may also reflect the degree to which the city is able to harness innovations in the design of low-energy sociotechnical systems [5,6], and in particular buildings [7,8]. Adding to the challenge, we must move from "transitions in cities" to "transitions of cities." [9].

Planning for future cities is therefore a daunting task, resulting in a wide spectrum of proposed city archetypes that each highlights different dimensions of sustainability [10]. Among these archetypes, "eco-cities" cover the broadest range of sustainability aspects including urban form, transport, safety and security, governance and technologies that support and enable a healthy environment, economics, society, culture and politics [10]. The eco-city, a concept first proposed in 1975 [11] and now widely referenced in academic literature [12], should therefore embody the key elements of sustainable cities [13] and avoid the fallacy of confusing city intelligence (e.g. a smart city) with city

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sustainability (e.g. a sustainable city). Indeed, the measures of success for an eco-city should be balanced across the three pillars of environment, society and economy, which is unfortunately often not the case [14].

In achieving such balance, the following eco-city attributes are often considered as important [15,16]:

1. land-use priorities that create compact, diverse, green and safe mixed-use communities around public transportation facilities;
2. transportation priorities that will discourage driving and promote access by proximity;
3. restoration initiatives for damaged urban environments;
4. affordable, safe, convenient and economically mixed housing;
5. social justice and improved opportunities for the underprivileged;
6. support for local agriculture, urban greening and community gardening;
7. promotion of recycling and resource conservation while reducing pollution and hazardous waste;
8. ecologically sound economic activities and discouraged hazardous or polluting activities;
9. promotion of simple lifestyles without excessive consumption of material goods;
10. public awareness of the local environment through education and outreach.

For reasons such as these, Masdar City in Abu Dhabi, the United Arab Emirates, has been frequently labeled as an eco-city in the making [17–20]. Indeed, the original vision behind the city is largely supportive of this ambition.

However, the plans for Masdar City have changed multiple times since construction began on the city in 2008. The timeline for full development of the city has been pushed out to at least 2030 and many of the original sustainability targets for the city have been reduced. History has many lessons to teach and, as shown in this Perspective, the unfolding story of Masdar City suggests that delivering a successful eco-city needs an inspiring but realistic discourse on sustainability that takes into consideration to the city's economic, social and political context.

2. The Masdar City of yesterday

Masdar City, which is located in the emirate of Abu Dhabi, began as a part of the broader Masdar Initiative. Masdar, which means “the source” in Arabic, was founded in 2006 by the Abu Dhabi government to diversify the UAE economy away from dependence on oil and gas and toward a more sustainable energy and economic system. Masdar is wholly owned by the Mubadala Investment Company, which itself is an Abu Dhabi owned enterprise formed in 2017 from the merger of Mubadala Development Company and the International Petroleum Investment Company. Mubadala Development Company, Masdar's parent company prior to the 2017 merger, was formed in 2002 with the mandate to support and facilitate the diversification of Abu Dhabi's economy [21]. Masdar was formed with a directive to advance sustainable energy through education, research and development, investment and commercialization. To achieve this mandate, Masdar was organized into four main business units as shown in Table 1.

Since its inception, however, Masdar has reorganized several times to reflect an evolving understanding of how the initiative could be successful in the rapidly changing clean energy space. The Industries Unit, for instance, was initially charged with developing a portfolio of clean energy production assets, the flagship of which was the thin-film PV manufacturing company Masdar PV [22]. Masdar PV closed down in 2014, however, amidst severe competition from Chinese competitors [23] and Masdar chose to then focus on just clean energy project development and investment rather than to try to compete in hardware manufacturing. This project development and investment unit was called Masdar Power and stood as a distinct unit alongside Masdar Carbon until both were brought under the umbrella of Masdar Clean Energy in 2013. Masdar City's operating structure was reorganized in 2010 when the city's business model was changed from project developer to master developer and integrator. The city became focused on development through the extensive use of outsourcing and strategic partnerships as opposed to the “self-develop and hold” concept, which was the basis for the original Property Development Unit.

In parallel to its change in business model, Masdar City also moved away from a zero-carbon strategy (Fig. 1) to one focused on carbon neutrality. For its buildings, Masdar City developed the Masdar Energy Design Guidelines (MEDG) that drew from, and in many cases exceeded, the most rigorous international standards for building performance, such as the German “PassivHaus” code [24]. However, the city's building sustainability targets were not based on standards adopted in the rest of Abu Dhabi.

This changed, however, when Abu Dhabi's Estidama program was initiated in 2010 by the Abu Dhabi Department of Urban Planning and Municipalities (DPM) [26]. The Estidama program is similar to BREEAM (British Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) in that it has a certification system called Pearls, which is a framework for the sustainable design, construction and operation of buildings, villas, and neighborhoods [27]. Pearls is a point-based system that ranges from 1 to 5 Pearls. A final Pearl rating is determined from accumulated points earned for meeting both mandatory and optional credits that fall under seven categories. A very small number of buildings in Abu Dhabi achieve a 5 Pearls rating because this level of certification requires a net positive contribution to the environment in terms of energy, water, and improving diversity and health of living systems. In Masdar City, all developed property must be at least 3 Pearls. This may seem like a conservative standard given the city's desire for sustainability. However, in Abu Dhabi 3 Pearls is comparable to LEED Gold and exceeds the minimum 1 Pearl requirement for all new buildings in Abu Dhabi and the minimum 2 Pearl rating for all government funded buildings in the emirate.

Following early re-organizations, in 2014 Masdar was structured around four main business units, Masdar Capital, Masdar City, Masdar Clean Energy, and Masdar Special Projects, as well as an independent research university, the Masdar Institute of Science and Technology [28]. Masdar Capital was a major investor in clean-technology companies around the world, while Masdar Clean Energy focused on the development of large-scale renewable energy and carbon abatement projects. Masdar Special Projects, which eventually became part of Masdar Clean Energy, was the provider of small and medium-sized renewable energy applications that address unique technology and deployment challenges. Masdar City was a special economic zone intended to serve as a model for commercially viable sustainable living. The Masdar Institute of Science and Technology was a graduate only university developed in cooperation with the Massachusetts Institute of Technology (MIT). Although not under the umbrella of the Masdar Corporation, the university was a key part of the Masdar concept. Located in Masdar City, it was the anchor for intellectual activity within the City.

The Masdar Solar Hub, launched in 2015, was intended to further the UAE's solar efforts via unique demonstration capabilities that were, and continue to be, part of the broader research and demonstration capabilities that Masdar City established in collaboration with Masdar Institute [29]. By 2018, Masdar City began addressing the eco-city agricultural dimension via several sustainable agriculture pilots with strategic partners, including the UAE Ministery of Food Security [30]. One of the showcase agriculture pilots was the 2 hectare Seawater and Energy Agriculture System (SEAS) undertaken by Masdar Institute's Sustainable Bioenergy Research Consortium (SBRC) with partners Etihad Airways, The Boeing Company, Safran, General Electric, ADNOC Refining and Bauer Resources [30].

Table 1
Original structure of the Masdar Initiative.
Source: [22].

Masdar units	Function
Carbon management	Develop a portfolio of clean development mechanism projects and a carbon capture and storage network in Abu Dhabi
Industries	Invest in clean energy production assets and develop a high-tech solar cluster
Masdar Institute of Science and Technology	Offer graduate degrees focused on the science and engineering of advanced energy systems and sustainable technologies
Property development	Build Masdar City, the world's first carbon-neutral, zero-waste city
Utilities and asset management	Develop a portfolio of renewable energy operating assets and strategic investments

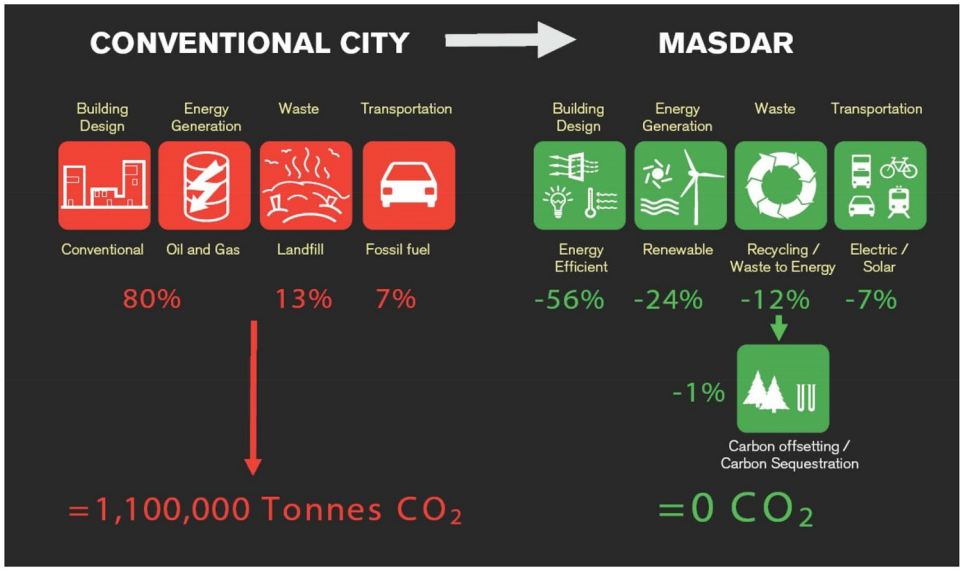

Fig. 1. Masdar City objective in 2008 to become a zero carbon entity. Source: [25].

Even though Masdar was a broad initiative with many components, Masdar City became the iconic feature that many associated most closely with the brand. Masdar City was to become a 6 square kilometer development located approximately 17 kilometers from downtown Abu Dhabi City. It was Masdar's vehicle to demonstrate a new paradigm in sustainable living through a combination of urban design and technology deployment. The originally announced plan for Masdar City (see Fig. 2) was that by 2016 it would be the world's first zero-carbon and zero-waste city with all of its buildings sitting on an elevated platform where 40,000 residents and 50,000 commuters would engage daily in educational, work and social activities [19].

As a relatively small development with significant financial backing from the Abu Dhabi government, it was apparent that Masdar City could be a test-bed for new technologies required to meet extremely demanding sustainability targets. This resulted in Masdar's early focus on environmental sustainability via architectural design and technology. The ultimate ambition of such focus was to capture economic benefits from the development of new, commercially valuable intellectual property.

In parallel to the development of technology roadmaps aimed at achieving these ambitions, Masdar undertook assessments to identify how the city could become in a short time a commercially viable clean-technology hub that is home to a diverse assortment of multinational companies, start-ups, research institutes and NGOs. The idea was to leverage the Masdar concept to create a version of Silicon Valley within the UAE. Partially due to the global financial crisis of 2008 and partially due to lessons learned from strategic assessments, Masdar City's development strategy was revised to have a more gradual pace and encompass fewer of the most expensive and challenging elements that were originally envisioned. The idea of having the entire city built on top of a podium with a personal rapid transportation network underneath is one such element that was eliminated in favor of a simpler and less costly approach to sustainable transportation.

Power, water and waste technology demonstration plans within the city were substantially downgraded due to regulatory challenges and the large scale required for meaningful demonstrations. Likewise, the state of the regional clean-technology market, an undeveloped local research and innovation ecosystem, and lack of local frameworks for attracting global companies made rapid and commercially viable development of a clean-technology cluster impossible within the timeframe initially planned for the city's development.

3. The Masdar City of today

Today, in late 2019, the Masdar Initiative looks different than it did. Only Masdar Clean Energy and Masdar City (now called Sustainable Real Estate) remain as major business units [31]. Masdar Capital became a part of Mubadala's investment arm before ceasing to exist and Masdar Special Projects has been folded into Masdar Clean Energy. The Masdar Institute of Science and Technology was merged in 2017 with the Khalifa University of Science, Technology and Research and the Petroleum Institute to form the new Khalifa University of Science and Technology. Although the Masdar Institute is a core part of Khalifa University, functioning as a research institute focused on clean and renewable energy and water and environment, it is no longer a degree granting university and no longer considered a core unit of Masdar. Masdar Clean Energy's mandate is little changed from the original vision and the Sustainable Real Estate unit is in charge of operating Masdar City and the Masdar City Freezone.

Masdar City's development strategy follows a new Master Plan (Fig. 3) and has adjusted to reflect the reality of developing a new city with many simultaneous ambitions, some of which have taken decades

Fig. 2. The Masdar City master plan in 2008. Source: [25].

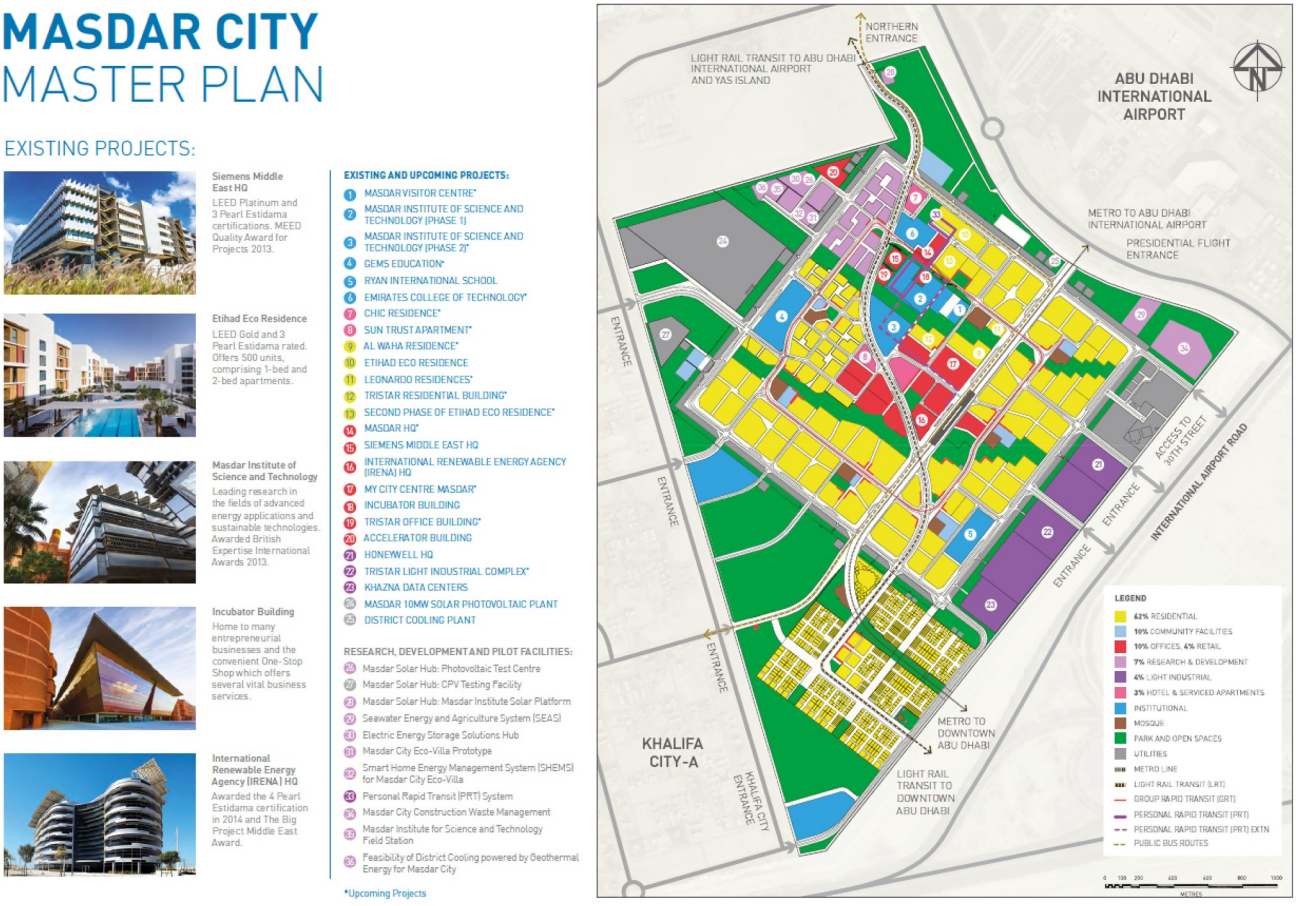

Fig. 3. The Masdar City master plan in 2018. Source: [33].

to realize internationally. In fact, the hope is that Masdar City's strategy today is built on an incremental approach with less focus on buildings and technology and more focus on the establishment of a new model for city form, structure and mobility. This necessary course correction is one that provides Masdar with the opportunity to avoid the fate of infamous “eco-cities” such as Dongtan in China, which was full of visions for sustainability that were never realized [32]. It would seem that Masdar City is now moving toward triple bottom line sustainability, which better aligns with the eco-city notion.

That is not to say the Masdar City of today is free of challenges. Among the most important of these is consistency in vision and stability in master plan while retaining sufficient modularity to adapt to the rapid pace of technological change taking place globally. The vision for Masdar in its early days was driven by its founding CEO, Dr. Sultan Al Jaber. Dr. Sultan was the primal force behind making Masdar a global brand and was at the helm of the initiative during the period of its grandest ambitions for sustainability [20]. Although he remains Chairman of Masdar, his greater commitment is in the development of the Abu Dhabi National Oil Company (ADNOC) since his appointment to the role of ADNOC CEO in 2016. Now as leader of a major oil and gas company, he naturally has less of a vested interest in the building of an eco-city.

While it is not the case that Masdar City is without direction, it is clear that planning and operational execution are now all the more important. On this point, the city has struggled to get on a course to attract the 1500 major multinational corporations and start-up companies that were originally planned to make the city a cleantech cluster [20]. Masdar, BP and the pre-merger Masdar Institute launched The Catalyst almost five years ago as technology start-up accelerator focusing on sustainability and clean technology [34] but so far the Catalyst has had little success in producing indigenous clean tech startups. There have also not been any major companies that have located in Masdar City specifically to undertake research and development that could help stimulate the formation of a cleantech cluster. Again, these are not issues fatal to the ultimate outcome for Masdar City but they do further reinforce the notion that the original vision is fading further away.

Although Masdar City is no longer pursuing its original grand vision of being zero-carbon, zero-waste and built on a nine-meter raised platform with an electric-powered rapid transport system beneath, environmental sustainability remains central to Masdar City's story. The city will now be “low-carbon” with the following sustainability objectives [35]:

- 15% reduction in embodied carbon of city construction materials (relative to comparable buildings in Abu Dhabi).
- 30% reduction in the embodied carbon of construction materials used in the construction of its buildings (relative to comparable buildings in Abu Dhabi).
- 40% reduction in the energy consumption of its buildings (relative to comparable buildings in Abu Dhabi).
- 40% reduction in the use of interior water (relative to comparable buildings in Abu Dhabi).

Further, all Masdar City buildings are constructed with low-carbon cement and 90% recycled aluminum in addition to other locally-sourced and verified materials [36], some of them shown in Fig. 4.

Regarding transportation, Masdar City initially planned to be car-free and leverage an iconic driverless Personal Rapid Transit (PRT) for nearly all vehicle-based movement within the city (see Fig. 5). This would have made Masdar City one of only five elite cities around the world to deploy a fully functioning PRT system, the others being Morgantown (1999), Rotterdam (1999), London (2011) and Suncheon Bay (2014) [37].

This plan no longer exists, however, and rather the city is promoting the use of electric vehicles and shuttles along with walking and other low-carbon modes of transportation. In 2018, Masdar City began its initial deployment of the Navya Autonom Shuttle, which is an autonomous, shared and electric mobility solution, as a follow up to the initial PRT concept [38]. Masdar, in collaboration with the Abu Dhabi Department of Transportation, has also launched the Gulf region's first fully electric bus with service from Masdar City to other locations in Abu Dhabi [39]. This public transportation initiative is complemented by an electric vehicle car-sharing program that Masdar has launched that allows users to rent by a Tesla vehicle by the minute on a pay-as-you-go basis [40].

Fig. 4. Sustainable materials in use at Masdar City. Source: Authors.

Masdar City's economic model now positions Masdar as both master builder and real estate developer. As real estate developer, Masdar leases land to third parties that are required to adhere to the development, design and sustainability guidelines established by the City. As master builder, Masdar develops buildings according to projected demand and subsequently owns these buildings. Masdar also builds to the demand of the government and private sector. Siemens’ headquarters building for the Middle East region, which is located in Masdar City, is an example of this model. The building is 3 Pearls and LEED Platinum, consuming 64% less energy than typical office buildings in Abu Dhabi. With all modes of development considered, approximately 10% of the city development will be in the form of offices such as Siemens' headquarters building and 62% of the city development will be residential [33].

Notably and supportive of Masdar City's stated sustainability ambitions, even the shopping malls opening in Masdar City, such as My City Centre, meet the Estimada 3 Pearls rating. Fig. 6 shows how the Carrefour hypermarket at My City Centre makes its sustainability performance visible to the public.

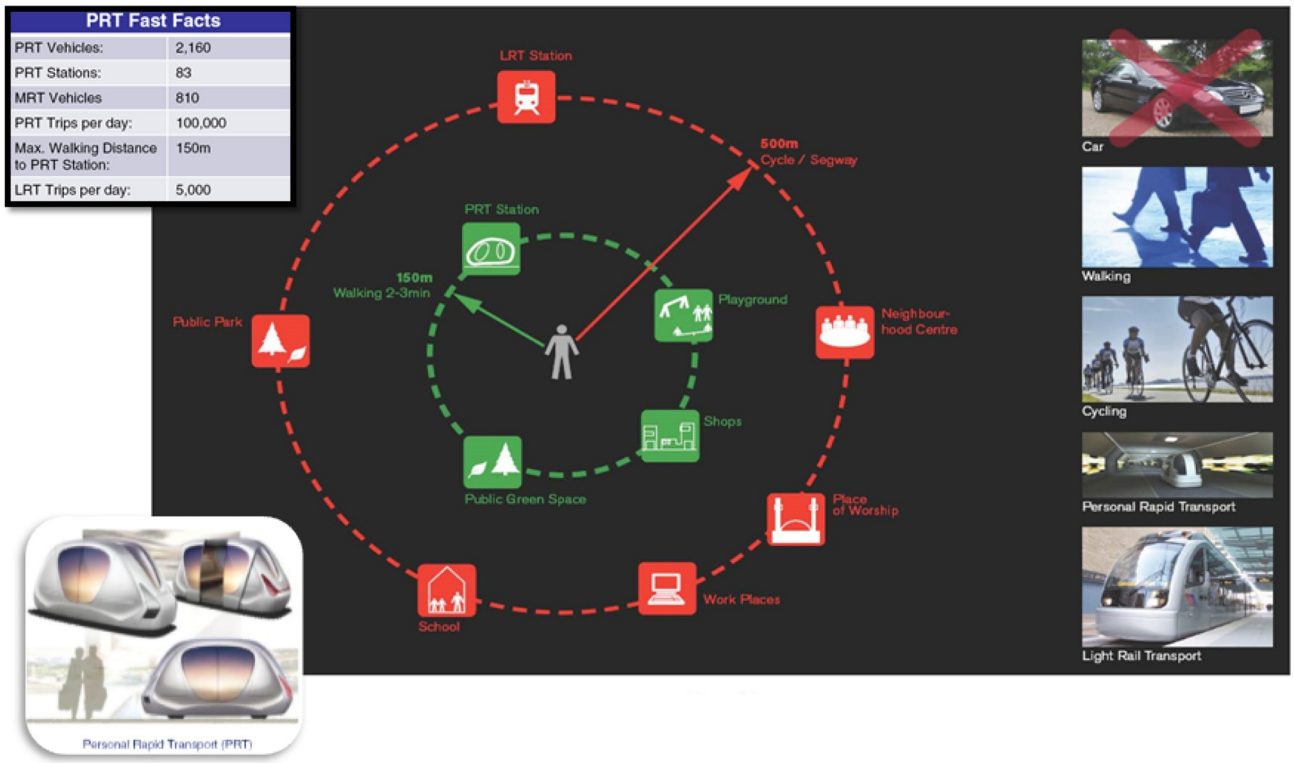

Fig. 5. Masdar City objectives in 2008 for transportation. Source: [25].

Fig. 6. Carrefour at My City Centre in Masdar City. Source: Authors.

4. The Masdar City of tomorrow?

Although Masdar City is obviously still a work in progress—in 2019, only about 10% of the city was complete or built (see Fig. 7) — Masdar projects that approximately 35% of the city's master plan will be completed between 2020 and 2025 [36]. Although the city currently has few residents, the plan remains to have up to 50,000 people living in the city and up to 40,000 people working and studying there daily. In order to support this goal, Masdar City's master plan is now aimed at creating social dynamics via a structure predicated on distinct neighborhoods linked by a network of sustainable mobility solutions.

This approach to city design comes from Masdar's recognition that city building blocks are neighborhoods and not large districts or downtown cores the size of Masdar City itself. Masdar City neighborhoods are residential as well as working neighborhoods, mixed-use neighborhoods, and R&D neighborhoods. Mobility between these neighborhoods and beyond the city is to be achieved via sustainable transportation modes that include pedestrian corridors, a group rapid transit corridor, and a light rail transit corridor. Further, the city continues to be designed for an optimum microclimate provided by passive design and natural cooling. This makes walking through city courtyards, urban squares and parks an option for sustainable mobility almost all year round.

In fact, the hope is that Masdar City has the opportunity to become a new model for urban mobility through integrated transportation, commerce and social interaction with the elimination of carbon emissions, traffic and urban heat islands. Although some may argue that Masdar City is too small for its evolving concept of interconnected neighborhoods to create a paradigm shift in urban design, the concept reflects Masdar City's emphasis on replicable design and now social sustainability as well.

The evolution of Masdar City has clearly followed a tortuous and oftentimes seemingly undirected path. There are many reasons for this, including its initially unprecedented ambitions for environmental sustainability, its development under Mubadala Investment Company,

Fig. 7. Ongoing construction at Masdar City in February 2019. Source: Authors.

which has an economic rather than environmental mandate, the socio-political context of the UAE and the impact of oil market volatility on Abu Dhabi's investment priorities. Although the underlying reason for Abu Dhabi's initial establishment of the Masdar Initiative and investment in Masdar City has been posited as a ploy by the UAE for political legitimization [41], the country has not been shy about its use of soft power to influence international opinion [42,43]. Further, the initiative and city undeniably created an opportunity for the country to take initial steps in transitioning from what has been coined as “petro-urbanism” [41] to sustainable development.

Unfortunately, key components of the Masdar Initiative that were fundamental to the Masdar City concept, such as the Masdar Institute of Science and Technology and Masdar's venture capital fund, are now either gone or have a different focus than was articulated in Masdar's original vision. Further, the economic mandate of Mubadala has continued to push Masdar City toward realizing economic returns over environmental ones. While this does not fully contradict the aims of an eco-city, it has led to criticism that Masdar City is only as sustainable as the economic and political system that it serves [17]. Although the concept of ecological modernization can be very positive for climate and society [44], it has been used in a rather derogatory manner with regard to Masdar City. Cugurullo suggests that the city's urban eco-modernization has hindered progress on environmental matters and social justice [17], largely due to the broader UAE socio-political environment in which the city operates. While it is true that the socio-political context of the UAE and broader region brings challenges to sustainable development [45,46], Masdar City has impacted positively national policy on sustainability as much as national policy may have negatively impacted the city.

For instance, even as early as 2010, it was clear that Masdar City

Fig. 8. A 10 Megawatt(MW) solar photovoltaic power plant at Masdar City. Source: Authors.

and its surrounding initiative were influencing awareness of sustainability regionally and globally [22] and since that time, environmental sustainability initiatives in Abu Dhabi have progressed significantly. Before the establishment of Masdar, Abu Dhabi heavily subsidized energy and water, had no sustainable rating system for buildings and had a power system almost 100% reliant on fossil-based energy resources [47]. Fast forward a decade later, and Abu Dhabi has become a regional leader in energy subsidy reform, renewable energy deployment and sustainable buildings [47,48]. Masdar spearheaded the UAE's first renewable energy policy in 2009 and it established precedence for large-scale renewable energy projects in the GCC through development of the Shams 1 Concentrated Solar Power (CSP) plant, which is a 100 MW facility that started operation in Abu Dhabi in 2013 [49]. As a testament to Masdar's influence on sustainability in the UAE, the UAE government officially highlights Masdar City and the broader Masdar Initiative as one of the pillars of the country's response to climate change [50].

Going forward, Masdar City can still achieve many of the attributes of an “eco-city” and develop its own, distinct low-carbon trajectory that compliments those of other cities with ambitious plans for carbon reduction [51]. Economic sustainability is clearly fundamental to the city's current plans and the most recent city master plan is aligned with key dimensions of environmental sustainability, particularly for a small, high income, innovator city archetype [52]. Although the city itself will not build out any major new renewable energy sources, the 10 MW solar photovoltaic (PV) plant and 1 MW of rooftop PV in the city (See Fig. 8) compliment a substantial build out of solar PV in Abu Dhabi [53] that will feed clean energy to the city.

5. Conclusion

In spite of the apparent progress Masdar City is making on the economic and environmental front, the city continues to deflect criticism about deviation from of its the original vision and lack of progress relative to the original plan. The original plan for Masdar City to be constructed through investment of $22 billion and completion over the course of 8 years has become more like investment of $10 billion and completion over the course of 20 to 25 years, according to city planners. Further, the city's social dimension, or lack thereof, has been a point of criticism [54], all the more so given that the city is currently years behind schedule and only 10% completed. Sustainability, it seems, is incredibly difficult to implement at the sheer scale of a city, even one being built from the ground up in a regime known for effective governance and planning. However, this can change if the planned residential build out produces positive social dynamics. The opening of the 2,500 square meter Masdar Park has created a potential new community destination that should help with this effort [55]. According to Masdar officials recently interviewed, the park has become a very popular evening destination for Emiratis, which is important to establishing a greater connection between the city and local society.

In conclusion and in reflection, the hope for Masdar City to become an exemplary eco-city is not yet lost. Masdar City, if it does work as currently planned, would underlie the importance of integrating city planning, passive design, energy supply, transport, water, and recycling efforts so that the entire community is low-carbon. However, challenges and barriers remain for the city in its path ahead. It may be, however, that the true legacy of the city will not be evolving into a model eco-city

but rather continuing to serve as a beacon for broader societal change toward sustainability in the UAE and the Gulf region. As noted in Teagarden's case study of Masdar City, "Masdar has introduced Emiratis to the concepts of climate change and renewable energy, and other regional governments are following the UAE lead" [20]. Societal regime changes often start from a niche that emerges at an opportune time. Perhaps Masdar City will stimulate progressive regional energy, climate, and transport planning as the need for sustainable urbanization becomes increasingly apparent. Or, failing that, Masdar City still represents an important omen with incredibly important empirical lessons for other cities around the world seeking to become more sustainable.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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